Navigation Performance of the 2018 InSight Mars Lander Mission

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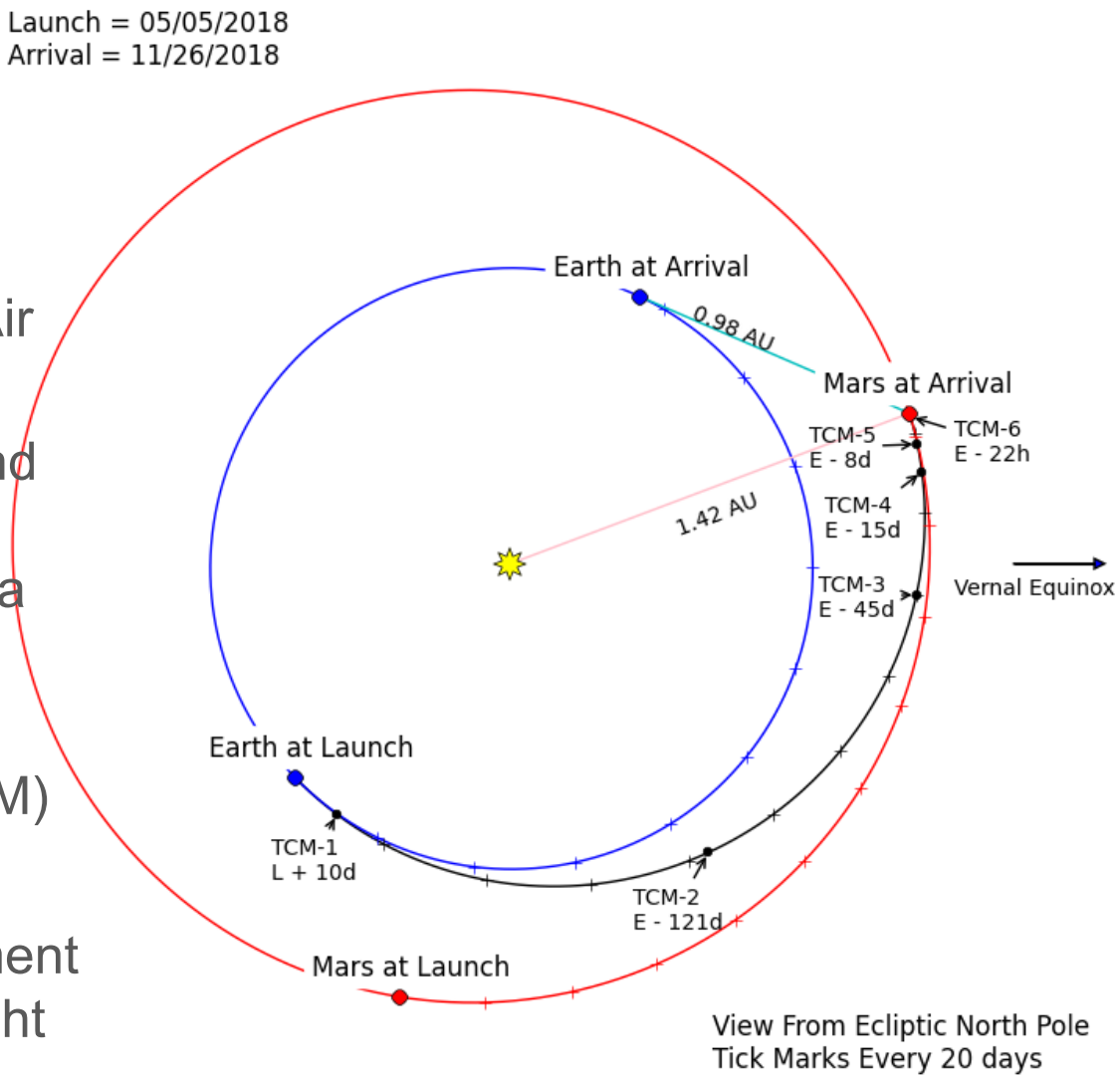
Cruise Overview

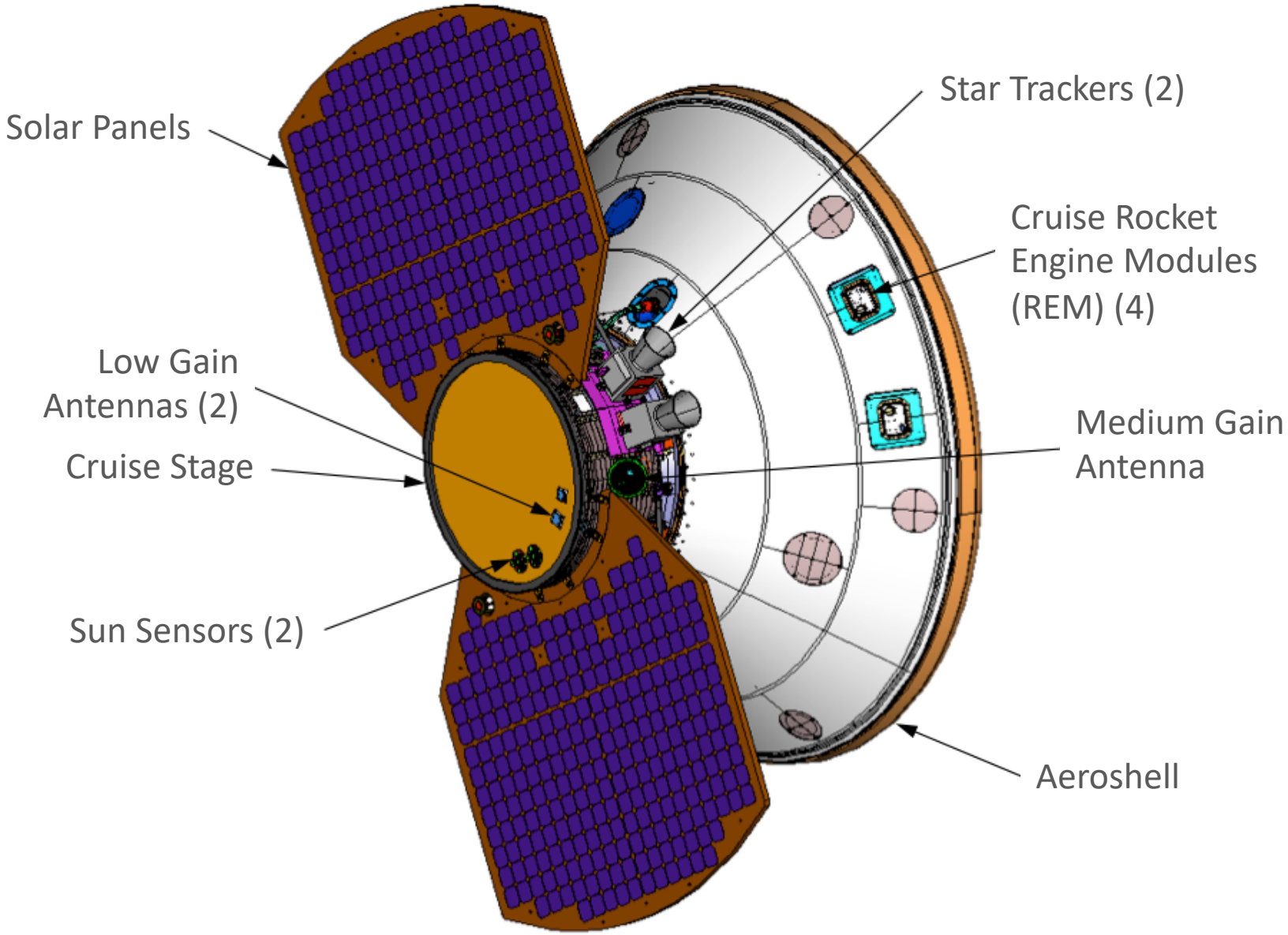
- Type I trajectory
- 3-Axis stabilized
- Attitude maintained by unbalanced thrusters
- Launch from Vandenberg Air Force Base
- Two-way Doppler, range and Delta Differential One-way Range (ΔDOR) collected via NASA DSN
- 6 scheduled Trajectory Correction Maneuvers (TCM)
- Active Thruster Calibration
- Delivery accuracy requirement of 0.15 degrees in entry flight path angle at Mars radius 3522.2 km



Cruise TCM Summary

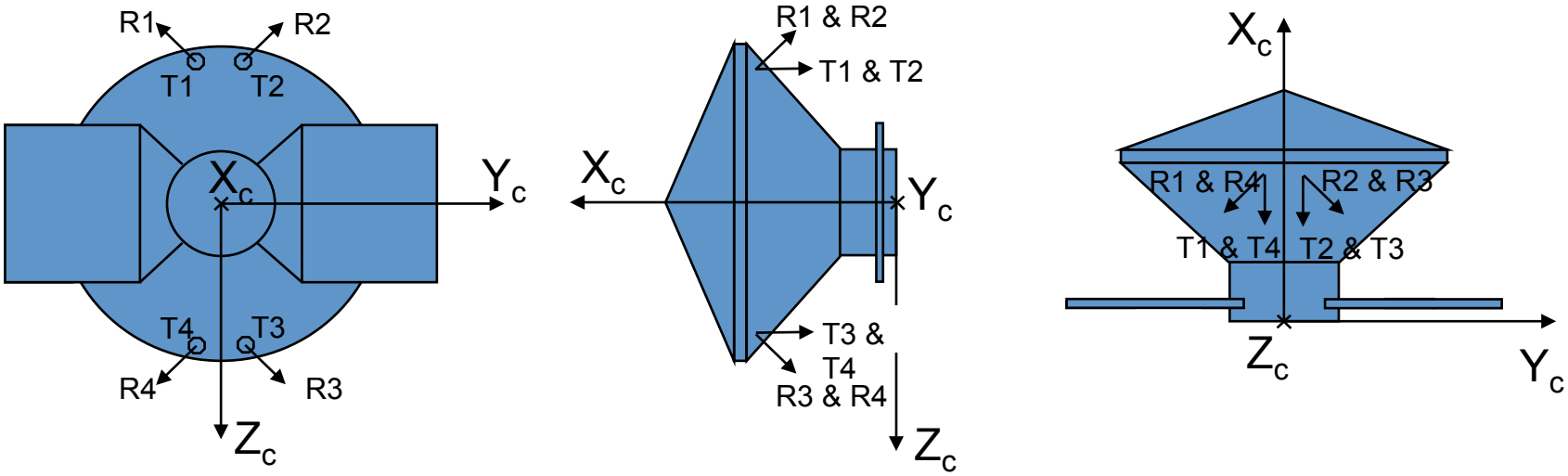
Event	Location	Date (UTC, 2018)	Magnitude (m/s)	Objective
TCM-1	L + 17d	May 22	3.78	Remove most of injection errors
TCM-2	E - 121d	July 28	1.50	Correct for TCM-1 and orbit determination errors
TCM-3	E - 45d	Oct. 12	0.167	Correct for TCM-2 and orbit determination errors. All subsequent TCMs target to desired landing site
TCM-4	E - 15d	Nov. 1	Cancelled	Correct for orbit determination and TCM-3 execution errors
TCM-5	E - 8d	Nov. 18	0.057	Correct for orbit determination and TCM-4 execution errors
TCM-5X	E - 5d	Nov. 21	N/A	Contingency - Same objectives as TCM-5.
TCM-6	E - 22h	Nov. 25 21:40	0.085	Final targeting to landing site.
TCM-6X	E - 8h	Nov. 26 11:40	N/A	Contingency – In case TCM-6 cannot be executed
TCM-6XM	E - 8h	Nov. 26 11:40	N/A	Contingency – If TCM-6 aborts or safes. Selected from pre-determined menu of validated maneuvers to maximize the probability of successful landing.

InSight Configuration (for Navigators)



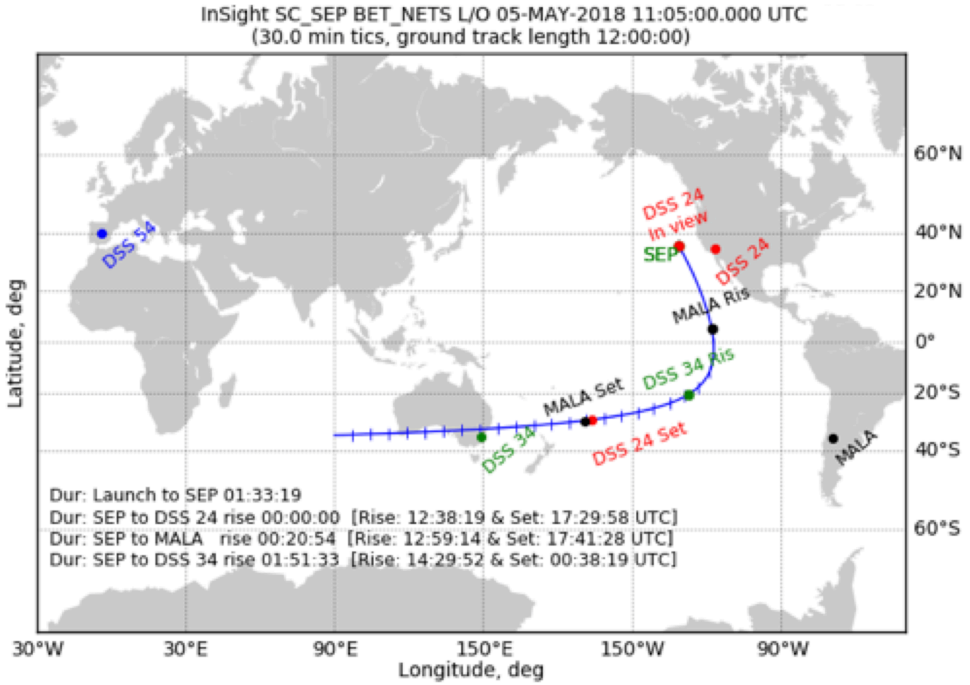
Thruster Configuration

- Each REM consists of a TCM thruster and an RCS thruster
- RCS thrusters were fired in pairs (nominally) to maintain an attitude deadband about the $+X_C$ axis
  - Every firing imparted a net ΔV about that axis
  - Furthermore, misalignments gave additional ΔV
- Off-sun pointing in early cruise caused expected one-sided deadbanding due to solar torques



Launch Geometry

- West Coast launch presented new challenges
  - S/C / Centaur Upper Stage separation delayed to DSN/Goldstone rise @ Launch+1.5 hours
    - One-way signal received at SEP+30 seconds indicated a healthy spacecraft
    - Two-way Doppler received at SEP+42 minutes
    - Range data received at SEP+59 minutes
  - DSN/Canberra rise only 2 hours later
  - Valid solution update for DSN frequency predicts was impossible due to short interval
  - Essentially used two initial acquisitions

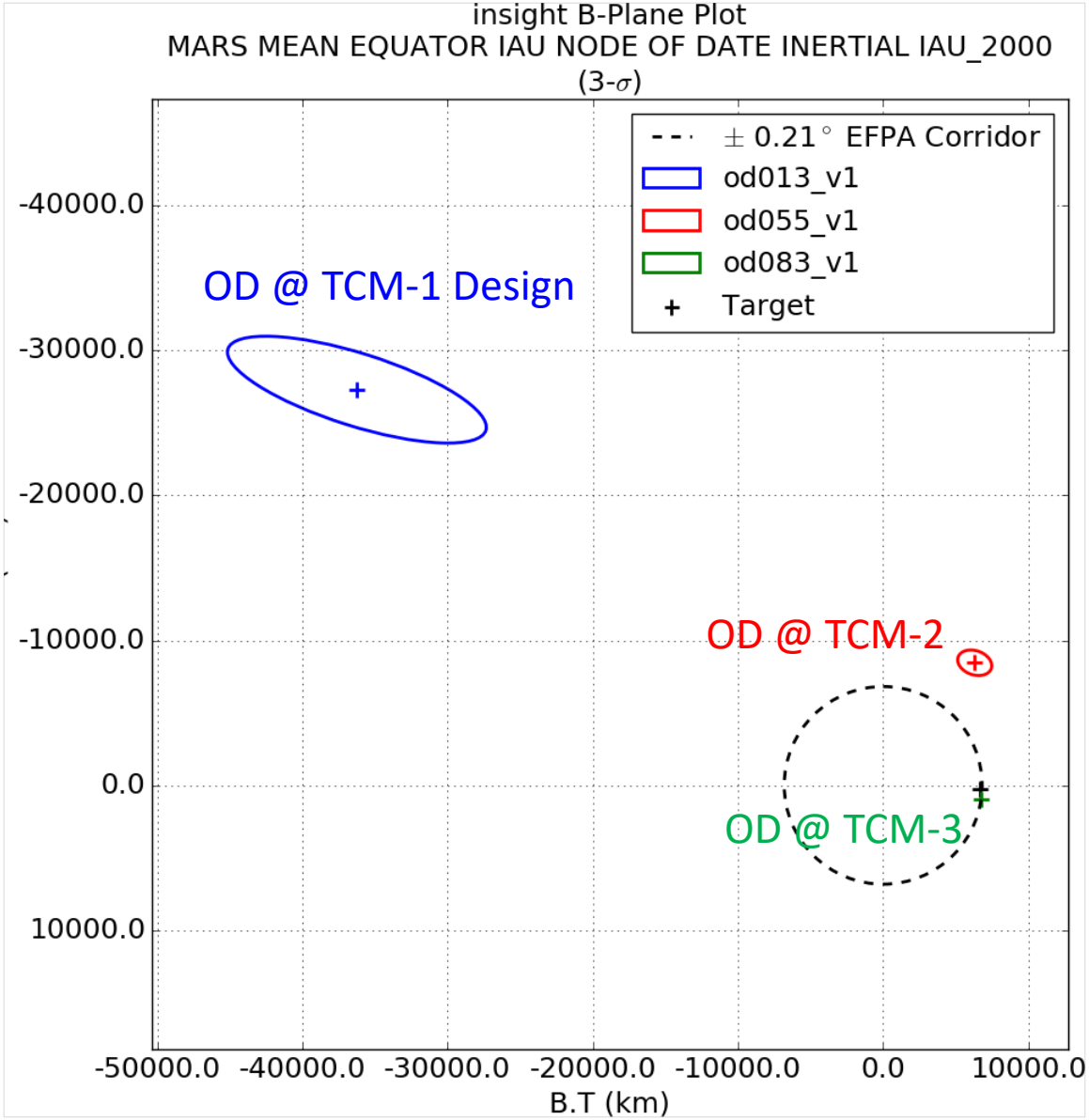


Post-Launch

- Soon after launch, it was clear that not all was as expected
  - Telemetry showed that the RCS system was firing much more than expected
  - In addition, orbit determination solutions showed anomalously high accelerations
- Lockheed Martin and JPL posited that an unusual level of outgassing was taking place, likely due to the 2-year storage of the aeroshell after the slip from the initial 2016 launch date
- TCM-1 originally placed at Launch+10 days to correct trajectory aimpoint bias (planetary protection) but this not advisable because of continuing high firing rates and the great uncertainty in predicting these small forces
- TCM-1 was delayed to Launch+17 days
- Additional “bake-out” was performed after TCM-1 at a thruster calibration attitude

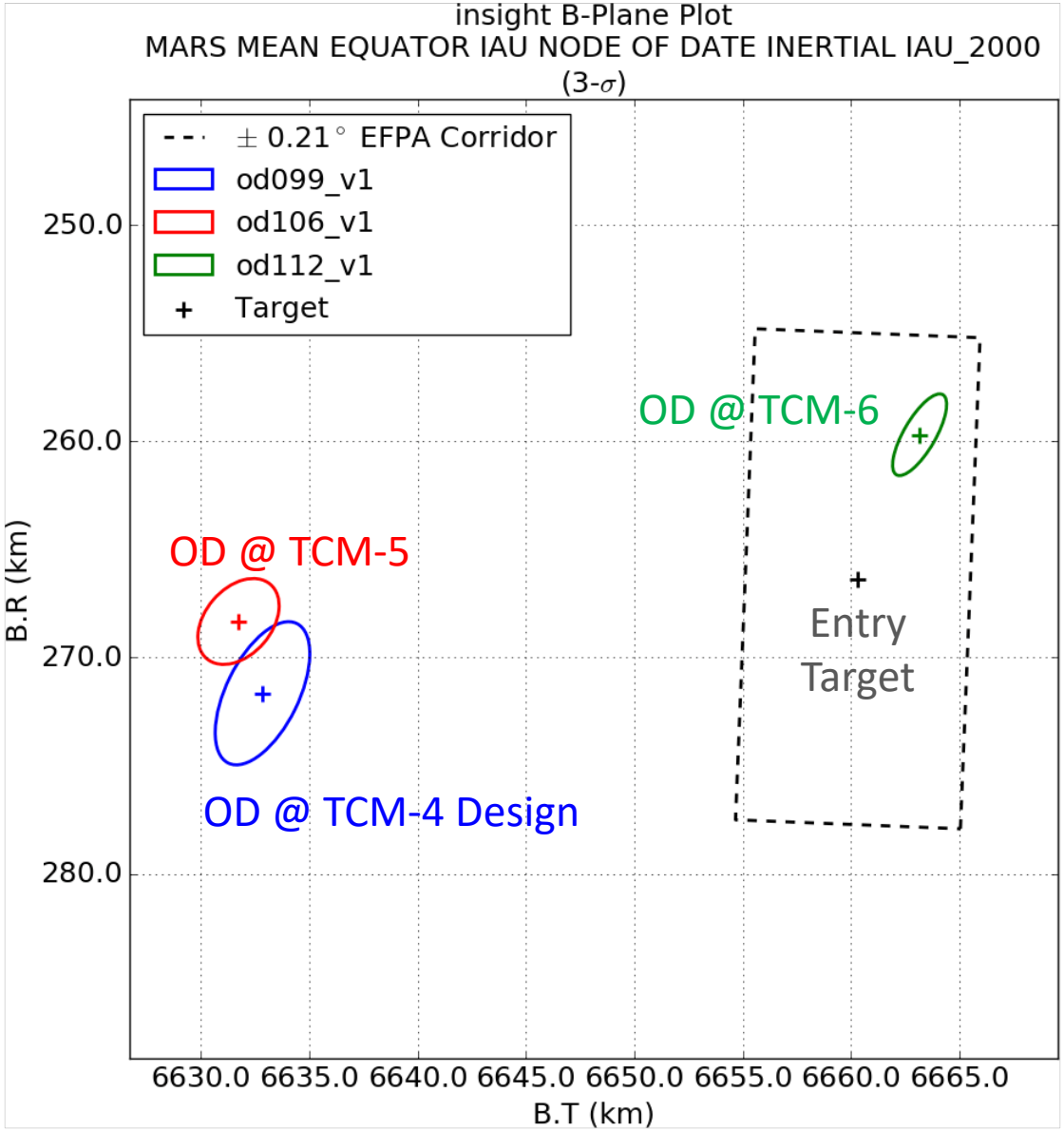
Early TCMs

- Navigation designed TCM-1 and TCM-2 in combination to achieve the desired entry target
- Active thruster calibration was performed on June 26, 2018 (L+52d)
  - This helped characterize the RCS thrusters
  - Frequent trending was also critical for orbit prediction
- Sun-pointing began on July 12, 2018 (L+68d) and deadbands tightened



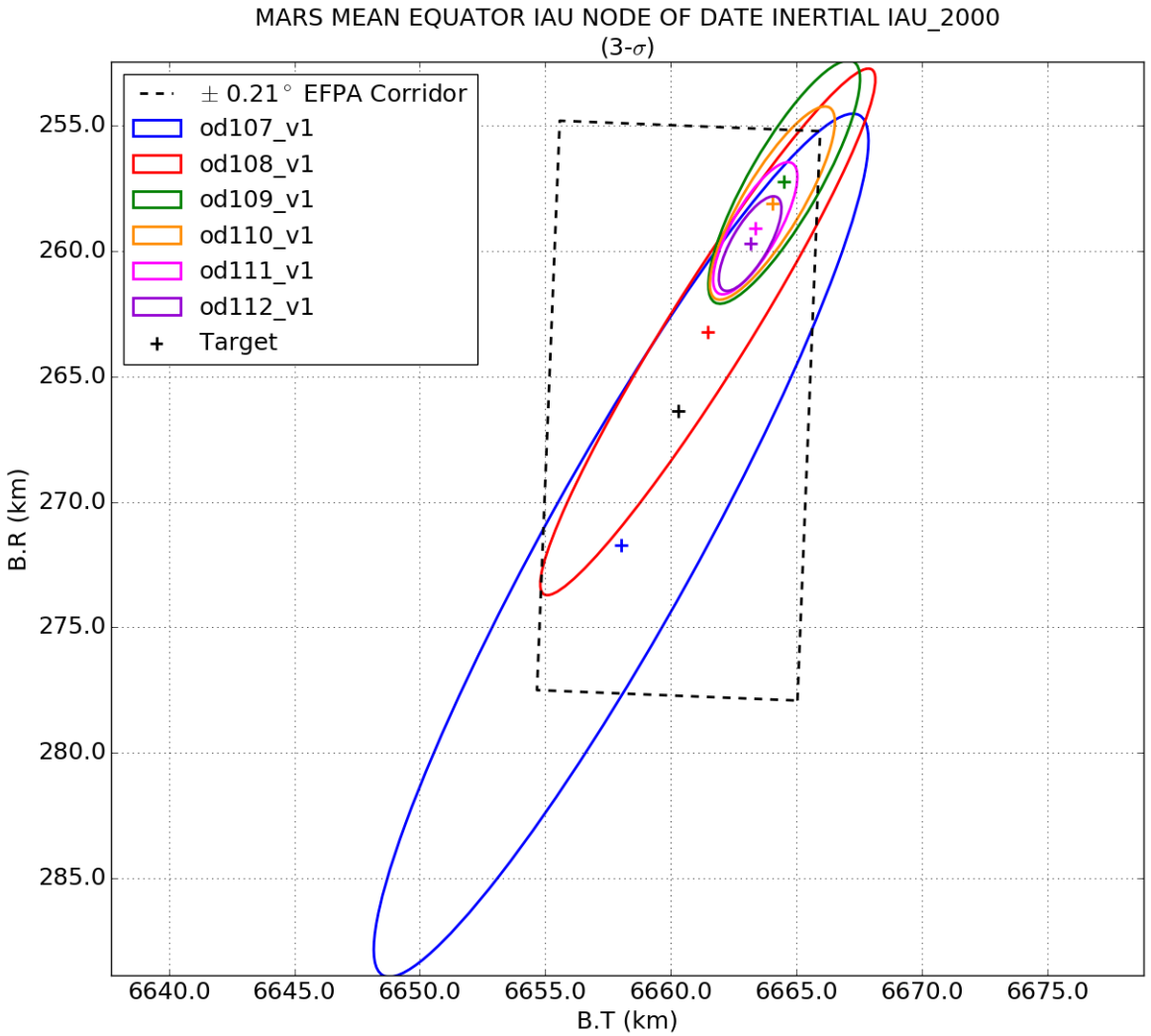
Approach TCMs

- TCM-4 (EDL-15d) would have been so dominated by its TCM execution errors that the target miss might increase, and was cancelled in favor of TCM-5
- TCM-5 (EDL-8d) was near enough to Entry that the effect of fixed execution errors was smaller, and so was executed



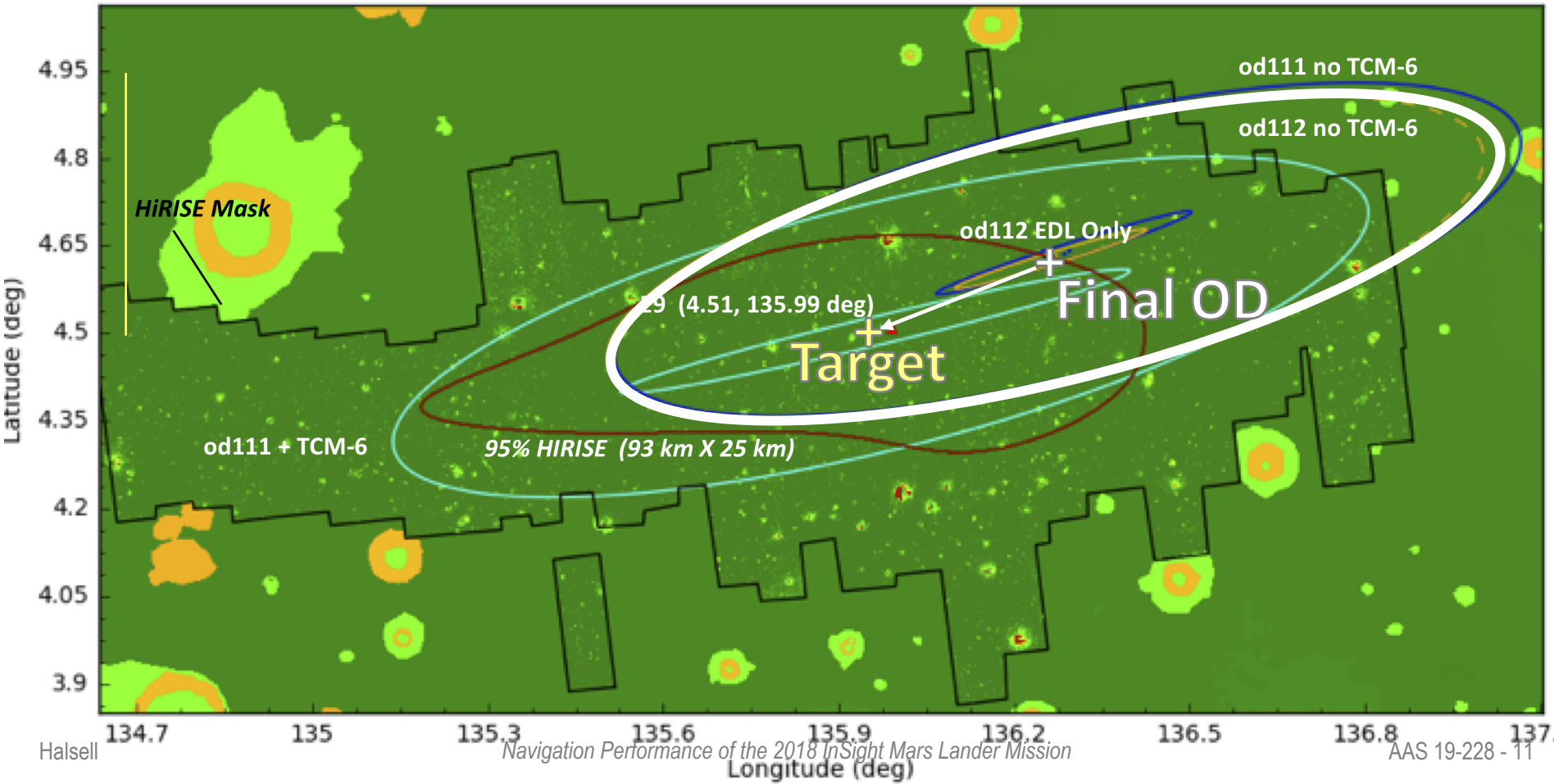
TCM-6 Design

- TCM-5 and TCM-6 were only 7 days apart, but it takes time and data to reconstruct maneuvers
- Plot shows the progression of daily solutions leading up to TCM-6 (with daily DDOR points)
- This was the first rapid maneuver turn-around for InSight
- Managing expectations is important!



TCM-6

- TCM-6 decisions were primarily based on terrain safety
- Navigation mapped delivery to the ground, including EDL error sources
- Final runouts showed the projecting landing just inside the 95% HiRISE contour, but TCM-6 was performed for caution



Final Landing Site

- Navigation delivery
  - 3σ entry flight path angle delivery (OD) = 0.0479 deg
  - 3σ entry flight path angle delivery (with TCM-6) = 0.1411 deg
  - Final OD distance from target < 7 km
- Final landing site distance from target = 19.4 km